EFFECTS OF GENDER AND FOOT POSITION ON ACCELERATION PATTERN OF KNEE AND HIP JOINT DURING DEEP SQUAT

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The purpose of this study was to investigate the effect of gender and foot position on the acceleration patterns of the knee and hip joints during deep squat. Twenty-two male and 10 female collegiate students participated in this study. All the participants performed a deep squat two times in neutral foot position (NFP), with the foot rotated externally by 15° (ERFP). A wireless triaxial accelerometer was attached on the right-side knee and hip joints of each participant. Acceleration data generated in the anterior-posterior (AP), medio-lateral (ML), and superior-inferior (SI) directions during deep squat were collected at 2000 Hz. Mixed analysis of variance ($p < 0.05$) was used to identify the interaction and main effects of gender and foot positions. The acceleration patterns of the knee joint during deep squat according to gender indicated differences between the AP and ML directions. The acceleration motion of the hip joint under the ERFP condition indicated a difference in the SI direction.

KEY WORDS: Acceleration, root mean square, gender, foot position, deep squat

INTRODUCTION: Squat is a typical resistance training exercise for the core muscles in sports training (Martuscello et al., 2013). Effective training of the target muscle while squatting and moving the load steadily through body movements is important (Kritz et al., 2009). Females have lower muscle strength than males, so females have more difficulty maintaining body stability during continuous deep squat, which requires the largest range of motion of the knee joint (Hewett, Myer, & Ford, 2006; Kritz et al., 2009). To increase body stability during deep squat, the base of support can be increased by external rotation of both feet in contact with the ground (Schoenfeld, 2010; Sriwarno, Shimomura, Iwanaga, & Katsuura, 2008). However, changes in foot position can be a factor that affects the movement of the knee and hip joints during deep squats, which is a form of closed kinetic chain exercise (Clark, Lambert, & Hunter, 2012). Therefore, the purpose of this study was to investigate the effect of gender and foot position on the acceleration patterns of the knee and hip joints during deep squat.

METHODS: Twenty-two male (age: 20.45 ± 2.26 years, height: 176.59 ± 5.42 cm, mass: 72.05 ± 8.56 kg) and 10 female (age: 21 ± 0.94 years, height: 162.1 ± 4.43 cm, mass: 56.36 ± 5.38 kg) collegiate students participated in this study. The participants signed an inform consent form approved by the institutional review board (IRB: 7001355-201705-HR-184) of the university and completed a health history questionnaire. All the participants performed a deep squat two times in neutral foot position (NFP), with the foot rotated externally by 15° (ERFP). For correct deep squat, the knee joint was flexed to the maximum so that the femur and shank contact each other during deep squat. The barbell, which is the external load mainly used in deep squat, was placed on the upper trapezius, and the external load was set to 50% of the body weight of each participant (McKean, Dunn, & Burkett, 2010). A wireless triaxial accelerometer (Delsys, Naetick, MA) was attached on the right-side knee and hip joints of each participant (Figure 1). Acceleration data generated in the anterior-posterior (AP), medio-lateral (ML), and superior-inferior (SI) directions during deep squat were collected at 2000Hz. The collected acceleration data were analyzed using MATLAB (version 9.0.0) to determine the root mean squares (RMS) of the three directions (Figure 2). Then, the

RMS values were converted to acceleration [g] (Kim et al., 2016). Statistical analysis was performed using SPSS 24.0 (IBS Corp, Armonk, NY), and mixed analysis of variance was used to identify the interaction and main effects of gender and foot positions. The level of significance was set at 0.05.

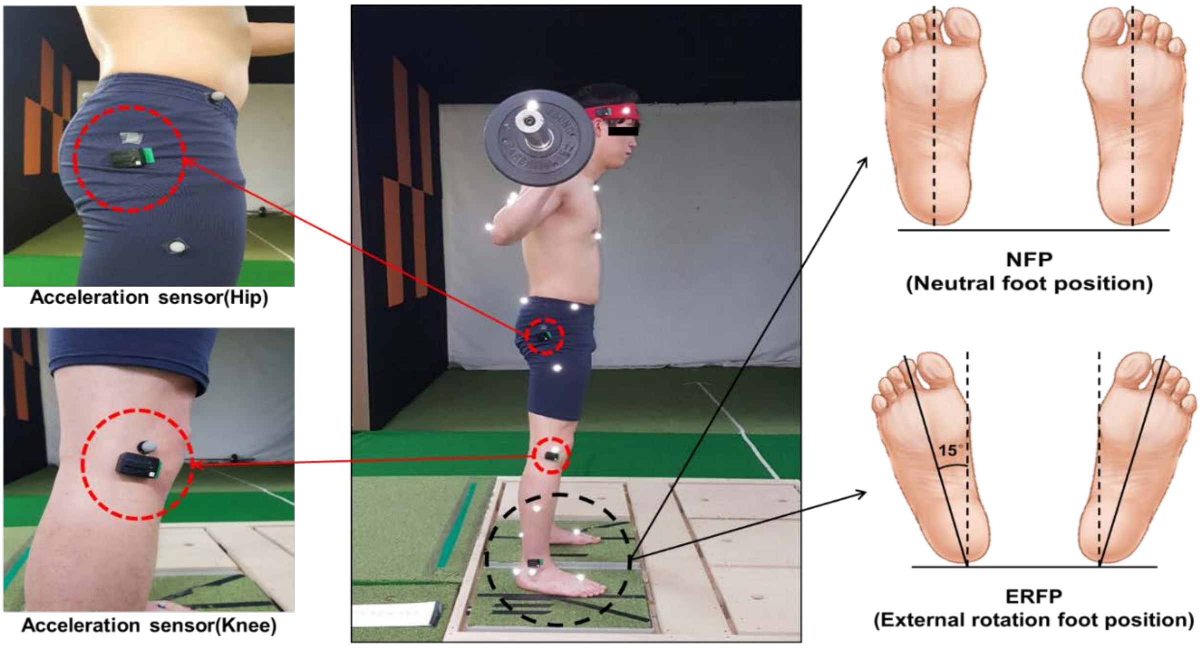

Figure 1: Attachment position of acceleration sensor and definition of foot position.

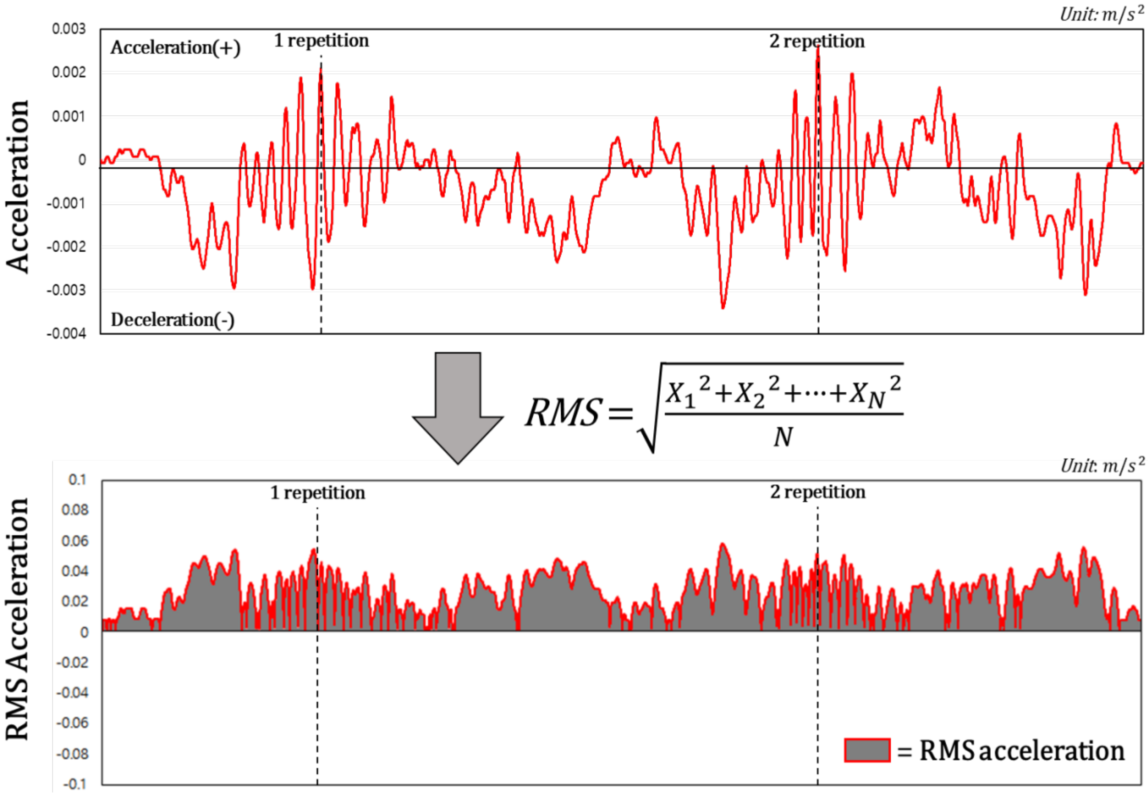

Figure 2: Processing of root mean square (RMS) value during deep squat

RESULTS: RMS acceleration values of the knee joint according to gender and foot position during deep squat are shown in Table 1. The interaction effect of gender and foot position during deep squat was significantly indicated in ML direction on the knee joint (F = 5.650, p = .024). The main effect of the knee joint indicated that the AP (F = 4.556, p = .041) and ML directions (F = 4.732, p = .038) had significant differences. The female group showed significantly greater RMS acceleration values than the male group in the ERFP condition of the AP direction (p = .014). By contrast, the male group had a significantly greater RMS acceleration value than the female group under both the NFP (p = .042) and ERFP (p = .045) conditions of the ML direction. The female group showed significantly greater RMS acceleration values than the male group according to foot position under the ERFP condition of the AP direction (p = .044). The RMS acceleration values of the hip joint according to gender and foot position during deep squat are shown in Table 2. The interaction effect of gender and foot position during deep squat was significantly indicated in the SI direction on the hip joint (F = 4.770, p = .037). The main effects of foot position were significantly different in the SI direction (F = 10.426, p = .003). The RMS acceleration value was significantly greater in the female group than in the male group according to foot position under the ERFP condition of the SI direction (p = .003).

Table 1: The results of ANOVA for acceleration RMS variables at the knee joint

Direction	RMS acceleration [g]				Main Effect		Interaction Effect
	Male		Female		Gender	Foot position	
	NFP	ERFP	NFP	ERFP			
Knee AP	0.430 (0.171)	0.416‡ (0.173)	0.525* (0.107)	0.563*‡ (0.056)	0.041*	0.273	0.024*
Knee ML	0.330† (0.117)	0.348‡ (0.132)	0.245† (0.071)	0.256‡ (0.058)	0.038*	0.176	0.742
Knee SI	0.858 (0.152)	0.861 (0.152)	0.807 (0.137)	0.785 (0.109)	0.251	0.364	0.223

Note. NFP = Neutral foot position, ERFP = External rotation foot position,
*= NFP vs ERFP, †=Male vs Female (NFP), ‡=Male vs Female (ERFP)
*,†,‡ significant difference at $p < 0.05$

Table 2: The results of ANOVA for acceleration RMS variables at the hip joint

Direction	RMS acceleration [g]				Main Effect		Interaction Effect
	Male		Female		Gender	Foot position	
	NFP	ERFP	NFP	ERFP			
Hip AP	0.325 (0.089)	0.319 (0.102)	0.276 (0.157)	0.251 (0.110)	0.156	0.183	0.383
Hip ML	0.487 (0.227)	0.474 (0.226)	0.458 (0.134)	0.451 (0.138)	0.743	0.190	0.705
Hip SI	0.854 (0.133)	0.858 (0.131)	0.865* (0.107)	0.885* (0.093)	0.691	0.003*	0.037*

Note. NFP = Neutral foot position, ERFP = External rotation foot position,
*= NFP vs ERFP, †=Male vs Female (NFP), ‡=Male vs Female (ERFP)
*,†,‡ significant difference at $p < 0.05$

DISCUSSION: The purpose of this study was to analyze the pattern of knee and hip joints according to gender and foot position during deep squat. The knee and hip joints are related to physical movement during deep squat (Fry et al., 2003). The participants of this study performed deep squat two times consecutively and we evaluated the acceleration of the knee and hip joints. As a result, the female group showed significantly higher RMS values than the male group in the AP direction. However, the male group showed significantly higher RMS values than the female group in the ML direction. According to foot position, the RMS values of the hip joint significantly increased under the ERFP condition of the AP direction as compared with those under the NFP condition. When the females, who had weaker muscle strengths than the males, performed deep squats under the ERFP condition, their hip joints moved smoothly in the SI direction. Thus, it is assumed that the ERFP increased the base of support and stability (Clark et al., 2012; Sriwarno et al., 2008).

CONCLUSION: The purpose of this study was to analyze the acceleration pattern of the knee and hip joints according to gender and foot position during deep squat. The acceleration patterns of the knee joint during deep squat according to gender indicated differences between the AP and ML directions. The acceleration motion of the hip joint under the ERFP condition indicated a difference in the SI direction. Therefore, when women perform resistance exercise through continuous deep squats, foot external rotation may provide more postural stability than the neutral foot position.

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